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INVESTIGATION OF THE FACTORS INFLUENCING THE PROPERTIES AND STRUCTURE OF FOAMED SLAG GLASS

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The effect of the particle size and mixing of batch on the structure and properties of foamed slag glass is examined. Samples of foamed slag glass were synthesized at different temperatures from batch with different mixing-grinding times. The mixing of the batch makes it possible to obtain foamed slag glass with improved macro- and microstructures.

Key words: slag wastes, resource conserving technology, construction materials, thermal insulation, foamed slag glass.

One of the most pressing problems for Russia is heat insulation: energy losses reach 40% of the total energy consumption or 4×10^8 tons conventional fuel per year. According to the statistical data much more fuel is expended on heating 1 m^2 in Russia than according to [1]. According to the Scientific-Research Institute of Construction Physics of the Academy of Architectural and Construction Sciences up to 45% of the total amount of heat consumed in Russia is used in buildings of which only 10% meet the modern standards for heat insulation. Estimates also show that the money saved on heating energy-efficient buildings equals up to 80% of total operating costs [2]. Thus, there is great promise in developing silicate heat-insulation materials possessing the advantage of organic (low density and thermal conductivity) and inorganic (durability, stability, dimensions, high moisture, steam and acid resistance and so on) insulation.

Another global problem of the power industry is the accumulation of wastes from the production and combustion of different types of fuel. Slag wastes from the combustion of coal in thermal power plants (TPP) are one of the main forms of such wastes. They occupy thousands of hectares of economically significant land, which as a result not only remain unused in the economy but are also contaminated by substances released from slags with time. For various reasons the volume of existing slag wastes comprises at least 5×10^8 tons.

In this connection the problem of developing technologies for salvaging slag wastes so as to obtain various materials and articles is becoming extremely pressing. The main application of slags is in the constructing industry. The main avenues for their use are presented in Fig. 1. For example, slags find application mainly as an aggregate in road construction and in concretes of different density. The production of articles by the piece based on slag wastes is the least developed avenue for salvaging slag wastes, even though the range of materials which can be obtained from slags is very large.

We and a number of scientists [3] are of the opinion that foam glass is a very promising material. In this connection the synthesis of foamed slag glass on the basis of slag wastes, a glass in which a part of the initial cullet is replaced with slag wastes, would make it possible to immediately solve several problems [4]. Specifically, the use of slag as a raw material lowers the cost of production and makes it possible to decrease the area occupied by the slag wastes that adversely affect the environment.

Previous investigations [5] have shown that the use of slag wastes in the production of heat insulating glass materials is very promising. It is repeatedly mentioned in the literature that there is a direction connection between the quality of foamed materials and their particle size and mixing quality [6, 7]. In this connection the aim of the present work was to study the effect of these parameters on the structure and properties of foamed slag glasses.

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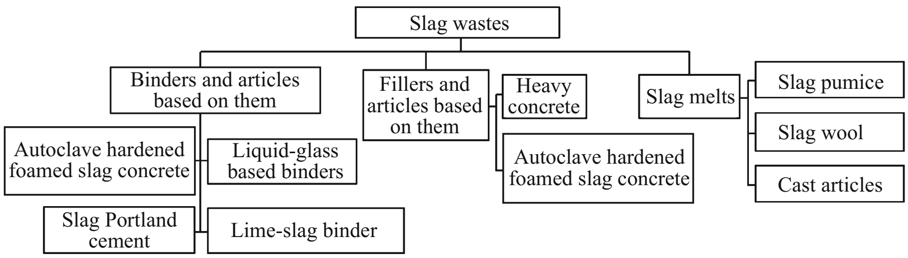

Fig. 1. The main applications of slag wastes.

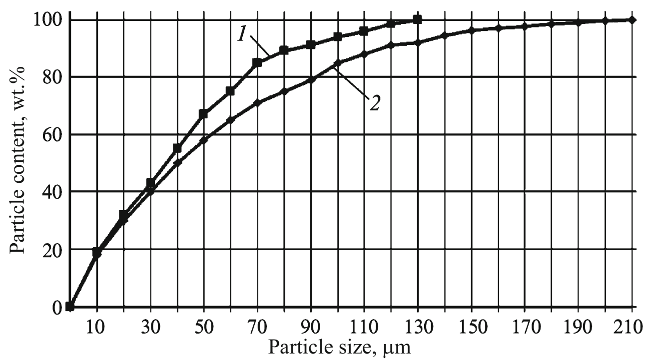

Fig. 2. Integral particle-size distribution curves: *1*) after grinding for 6 h; *2*) no grinding.

In [8] it was determined that the optimal foaming agent for the synthesis of foamed slag glass is anthracite, which makes it possible to obtain closed, isolated pores with stable sizes. Thus, the optimal composition of foamed slag glass was found to have the following oxide content (%): 63.56 SiO_2; 8.32 Al_2O_3; 4.14 Fe_2O_3; 2.27 CaO; 5.37 MgO; 1.55 K_2O; 10.57 Ma_2O; and, 4.22 B_2O_3. The main raw material components of the initial batch were cullet, slag from the Novocherkassk condensation electric power plant (CPP), sodium borate and anthracite.

The preparation of the raw material components comprised preliminary rough milling and sieving to particle size less than 200 μm. Then, the raw components were placed in a ball mill with batch/milling-body ratio equal to 1 : 2 and mixed with the batch being fine-ground at the same time (referred to below as mixing-grinding). At definite times five samples of batch were extracted from the drum by quartering to determine the dynamics of the variation of the properties of the batch. The samples were extracted after 0, 0.5, 1, 2, 4, 6, 8 and 10 h.

The dispersity of the batch was determined at each time interval on the basis of the samples extracted. The dispersity was determined with a NanotracTM Ultra laser analyzer from Microtrac Inc., capable of determining particles as small as 0.01 μm. The computed average determinations are presented in Table 1 and Fig. 2. It should be noted that the batch was subjected to grinding, so that the particles had an irregular, nearly spherical shape (in what follows 'size' is taken to mean the diameter).

It is evident from Table 1 that continuing mixing-grinding beyond 6 h is impractical because the properties of the batch change very little. This is explained by the fact that the batch is prone to agglomeration, which makes further mixing-grinding inefficient. For this reason, a comparative analysis of the particle sizes in batch not subjected to mixing-grinding and in batch subjected to mixing-grinding for 6 h is presented in Fig. 2. We also note that Fig. 2 shows an integral particle distribution curve, i.e., it shows the percentage content of particles in a sample smaller that the size indicated.

It is evident from Fig. 2 tonshat mixing-grinding for 6 h made it possible to increase the number of particles smaller than 50 μm from 58 tonso 67% and particles smaller than 100 μm from 85 to 94% and the maximum particle size increased by 90 μm.

Samples for determining the effect of mixing-grinding on the structure and the main properties (density, water absorption, ultimate strength in compression and thermal conductivity) of foamed slag glass were synthesized from the samples extracted.

To determine the average density five samples of each specimen were synthesized at temperatures 800, 825, 850 and 875 °C. The values of the average density, presented in Table 2 and Fig. 3, were determined. The water absorption for all samples did not exceed 3%.

TABLE 1. Dependence of the Batch Dispersity on the Grinding Time

Dispersity index	Mixing-grinding time, h							
	0	0.5	1	2	4	6	8	10
Particle size, μm:								
maximum	209	192	176	158	134	124	122	121
average	47.84	47.37	46.09	44.87	42.25	39.43	39.29	39.22

TABLE 2. The Density of Foamed Slag Glass Samples Versus the Batch Mixing-Grinding Time and Sintering Temperature

Sintering temperature, °C	Density of foamed slag glass samples, kg/m^3, with mixing-grinding times, h							
	0	0.5	1	2	4	6	8	10
800	798.53	764.68	753.29	711.58	684.42	651.44	643.87	637.62
825	768.18	744.52	702.74	657.97	647.52	606.61	595.45	592.18
850	563.78	502.79	525.96	469.63	442.27	422.68	412.15	408.27
875	545.85	478.01	459.56	442.64	416.45	–	–	–

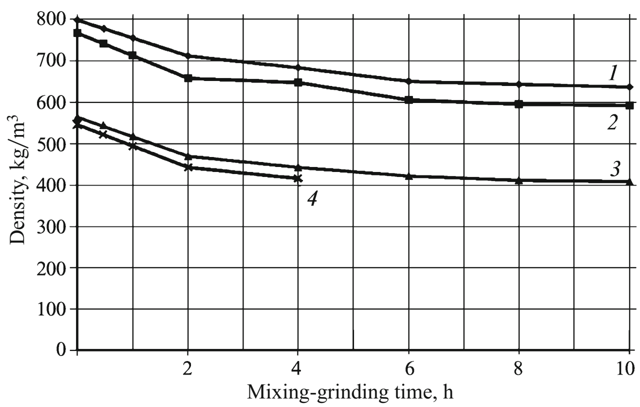

Fig. 3. Density variation versus the mixing-grinding time and sintering temperature: *1*) sintering at 800°C; *2*) at 825°C; *3*) 850°C; *4*) 875°C.

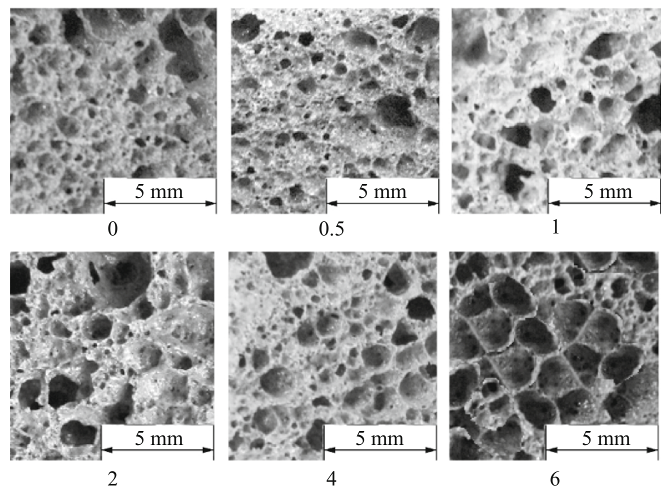

Fig. 4. Change in the structure of foamed slag glass versus the mixing-grinding time (indicated beneath each panel, h).

The following conclusions can be drawn from the data presented:

– during the mixing-grinding operation the average particle size changes by 18% from the initial value; therefore, the density reduction is related not only with the change in the average particle size but also with the more uniform distribution of the foaming agent in the batch;

– the mixing-grinding time and the density of the samples are related inversely; mixing-grinding for 6 h and sintering temperature 850°C were found to be optimal; the optimal average density is 422.68 kg/m^3; increasing the temperature to 875°C is impractical because the samples subjected to mixing-grinding for 6 h or longer melted at this temperature, so that sintering at this temperature was excluded from subsequent studies; the density reduction in all other samples at the same temperature is due to an increase of the pore size with their nonuniform pore size distribution being preserved, which adversely affects the thermal conductivity and strength of the material.

To determine the change in strength with a change in density the ultimate strength in compression was determined for samples not subjected to mixing-grinding and for samples mixed for 6 h.

The results presented in Table 3 show that even though the density reduction is significant the strength of the material remains at a level corresponding to the commercial analog; the thermal conductivity of the samples subjected to mixing-grinding was less than 0.08 W/(m · K), which also corresponds to the indices of the analogs.

The change in the structure of the foamed slag glass as a function of the mixing-grinding time was investigated at sintering temperature 850°C. The results are presented in Figs. 4 and 5.

It is evident from Figs. 4 and 5 that as the mixing-grinding time increases, the pore distribution in the samples becomes more uniform and the volume of the material without the pores decreases. In addition, after 6 h mixing-grinding the structure of the samples is nearly ideal: pores of size 1 – 2 mm are divided by a thin wall of the material. Such a structure corresponds to materials with high heat-insulation properties.

TABLE 3. The Ultimate Strength of Foamed Slag Glass Samples in Compression versus the Sintering Time and Temperature

Batch mixing-grinding time, h	Ultimate strength in compression, MPa, at sintering temperature, °C		
	800	825	850
0	3.25	2.86	2.66
6	3.04	2.64	2.27

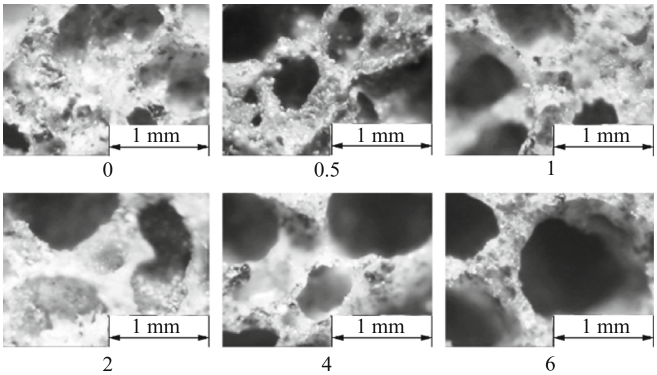

Fig. 5. Photomicrographs of samples with different mixing-grinding times (indicated beneath each panel, h).

In summary, it can be concluded that the investigations made it possible to determine the optimal parameters of the factors for synthesizing foamed slag glass comprising a light-weight heat-insulation material with uniformly distributed pores and adequate strength.

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